COLUMBIA RIVER TEMPERATURE TOTAL MAXIMUM DAILY LOAD

TECHNICAL ANALYSIS

Why Develop a Model?

- To determine important processes that affect river temperature

- To quantify the relative impact of different human activities on river temperature

- To run “what-if” scenarios

Goals of Model Development

- Develop a temperature model that:
  - accurately simulates river temperatures
  - supports a TMDL analysis

- Keep it non-proprietary, computationally simple and flexible

- Conduct Peer Review

- Build interface and guide for other users

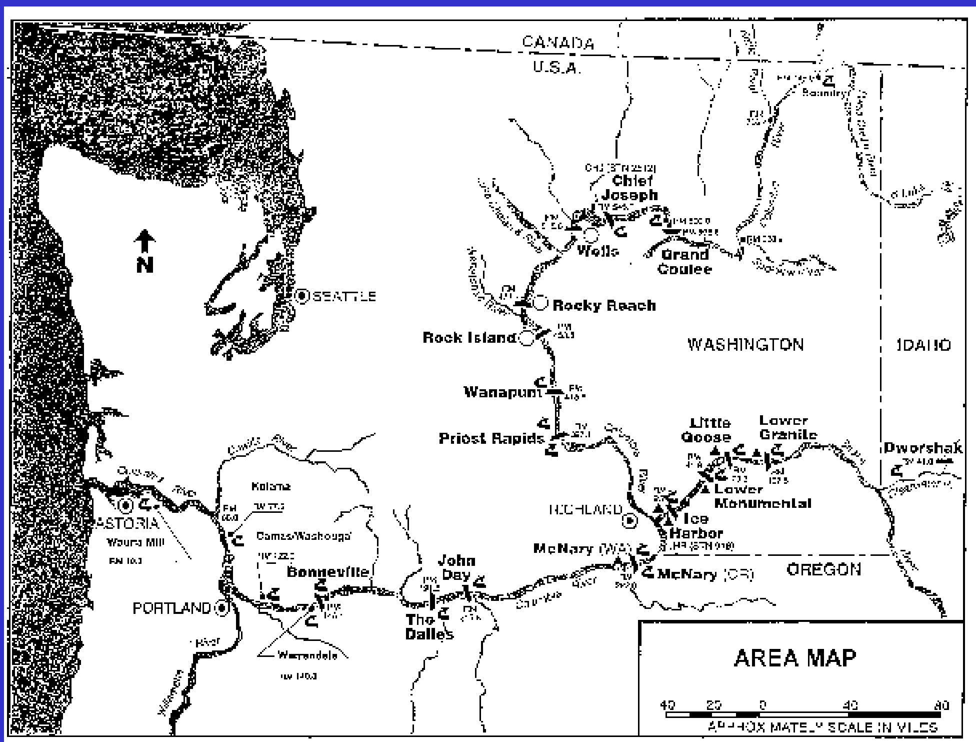
Model Name

- **River**
- **Basin**
- **Model developed in EPA Region**
- **10**

- **RBM10 is written in Fortran code and can be adapted to simulate any large scale river**

COLUMBIA RIVER

Scale of Analysis - Regional



Geographic Boundaries of Model

- **COLUMBIA RIVER from International border to Bonneville Dam**
  - **extension to Astoria in progress**
- **SNAKE RIVER from Brownlee Dam to confluence with Columbia**
- **CLEARWATER RIVER from Orofino to confluence with Snake**

BACKGROUND CONSIDERATIONS

Water Quality Standards

- Oregon and Washington Standards for Temperature require evaluation of natural conditions
  - Need to estimate temperatures in both impounded and un-impounded conditions

System Features

- Run-of-River Reservoirs
  - Vertical temperature stratification relatively low
  - Water surface elevation is relatively constant
    - points to potential utility of 1-D model with constant impoundment elevation
    - previous 1-D studies of Columbia River

Available Data

– **On the one hand…**

  - **Long term records are available for meteorology, tributary flow, and water temperature, enabling:**
    - **long term simulations**
    - **evaluation of system variability, and**
    - **comparison of simulations to monitored temps**

Data Limitations

- On the other hand…
  - Mainstem Temperature Monitoring
    - Monitoring at Dams Not Designed for Assessment of River Temperature
    - Limited Quality Control/Quality Assurance
  - Tributary Temperature Monitoring
    - Discontinuous Record
    - Unknown Quality Control/Quality Assurance
  - Meteorology
    - Limited Geographical Coverage

HOW TO ESTIMATE RIVER TEMPERATURE?

Two Ways to Estimate Temperatures

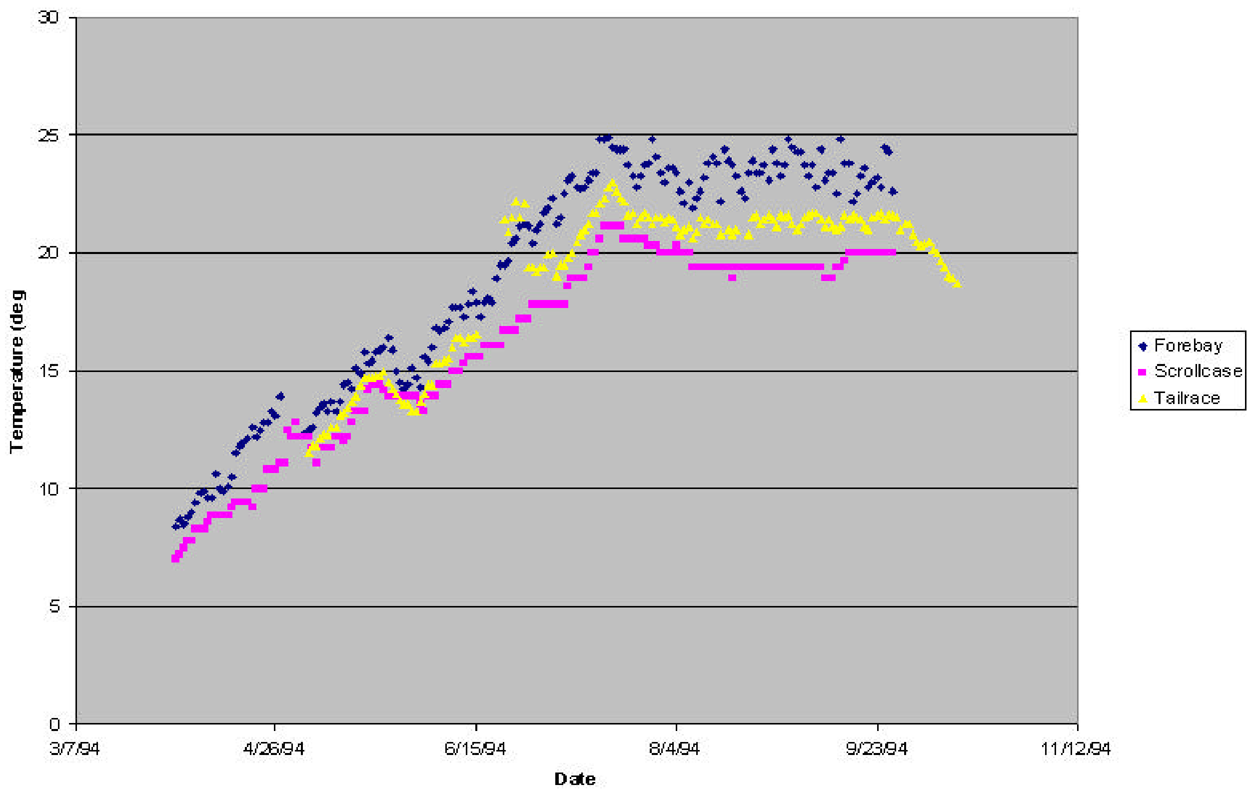
- River Temperature Measurements (Measurement Model)
  - Long term scroll case readings at dams
  - Scarce data from unimpounded river
- Energy Budget (Process Model)

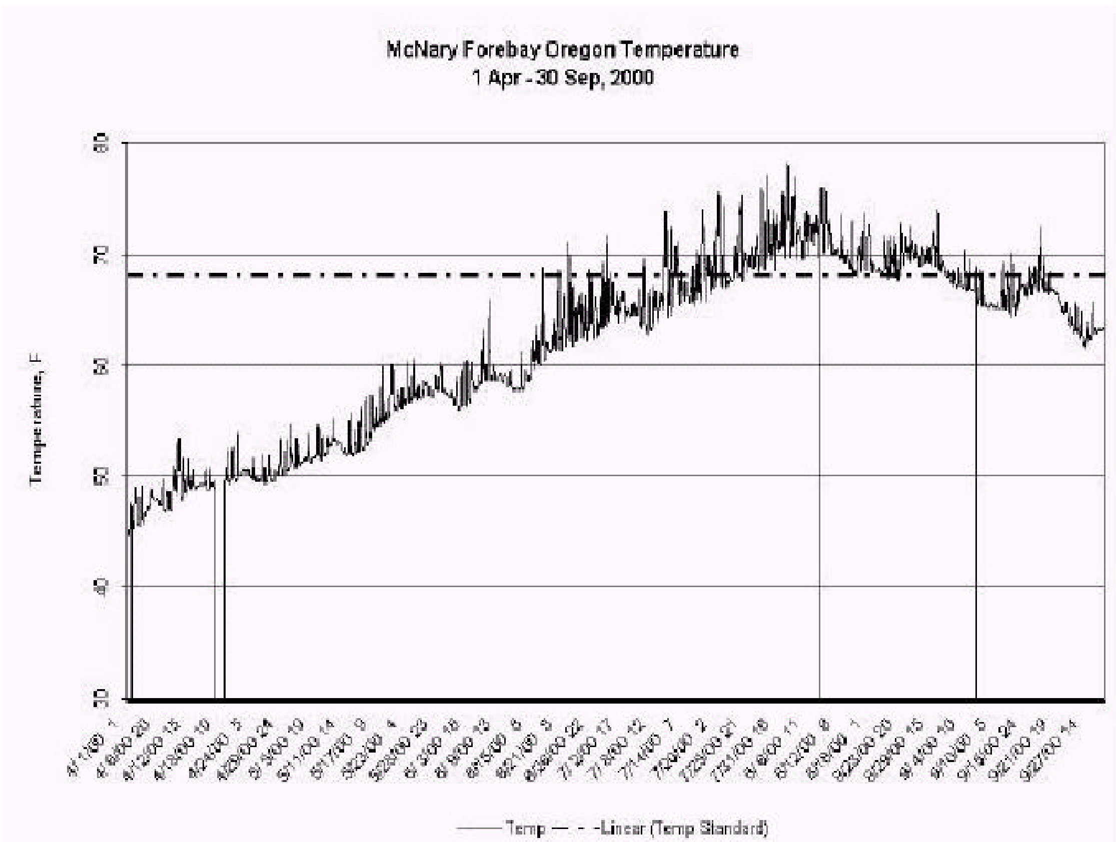
MEASUREMENT MODEL

Concept for Measurement Model

- Cross-sectionally averaged river temperatures can be estimated based upon:
  - Temperature Measurements at Dams (Scroll Case, Forebay, and/or Tailrace)

Comparison of Daily Water Temperatures at the Scroll Case, Forebay and Tailrace of Ice Harbor Dam, 1994




McNary Forebay Oregon Temperature
1 Apr - 30 Sep, 2000
Temperature, F
80
70
60
50
40
30
Temp
Linear (Temp Standard)

MEASUREMENT MODEL

$$T_{\mathbf{Actual}} = T_{\mathbf{Observed}} + n$$

TRUE STATE OF TEMPERATURE | *TEMPERATURE MEASUREMENT* | *MEASUREMENT ERROR*

PROCESS MODEL

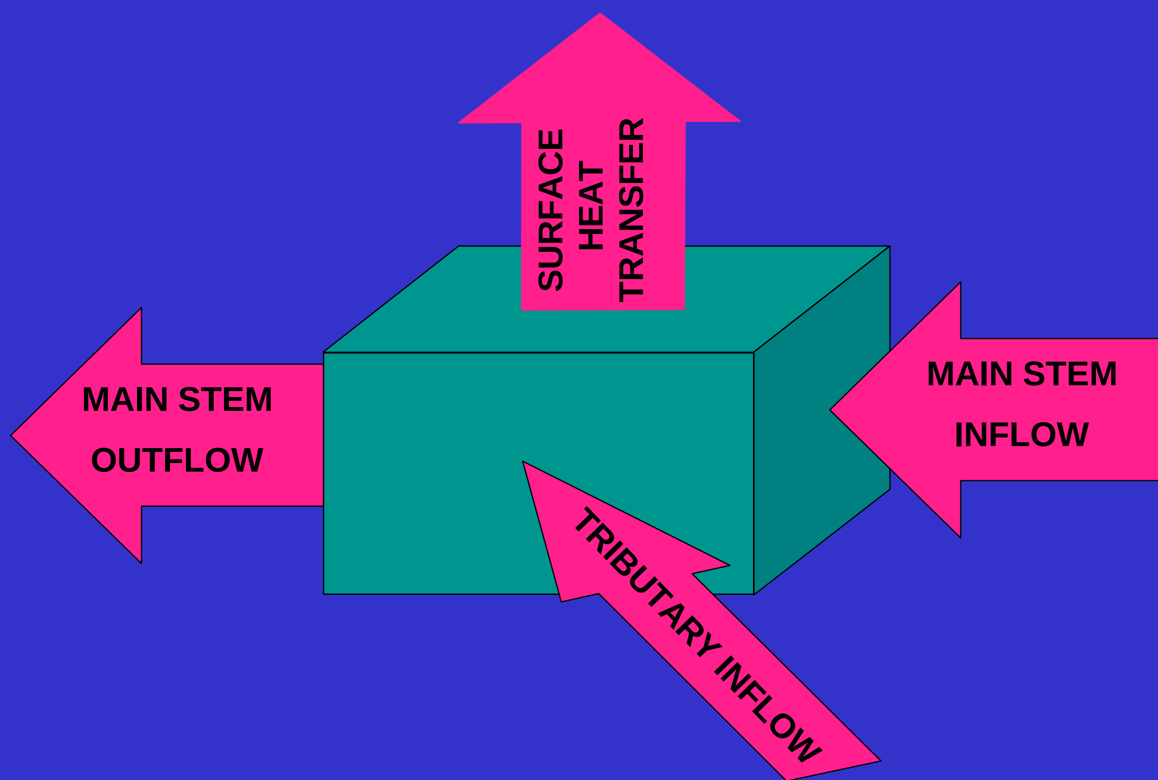
Why Do We Need Process Model?

- We need to estimate temperatures under un-impounded conditions for which measurement data is scarce
- We have conflicting measurements
- We do not have measurements at all river locations of interest
- We need to estimate influence of different sources

Concept for Process Model

- Cross-sectionally averaged river temperatures can be estimated based upon:
  - river flow and geometry
  - surface heat exchange, and
  - advected river and point source heat

ONE-DIMENSIONAL ENERGY BUDGET MODEL



ONE-DIMENSIONAL ENERGY BUDGET MATHEMATICAL MODEL

$$\frac{d(VT)}{dt} = Q_{in}T_{in} - Q_{out}T_{out}$$

CHANGE IN ENERGY — INFLOW ENERGY — OUTFLOW ENERGY

$$+ Q_{trib}T_{trib} + \frac{q_{surf}A_{surf}}{r\ C_{p}} + e$$

TRIBUTARY ENERGY — SURFACE ENERGY EXCHANGE — MODEL ERROR

INFORMATION NEEDS

General

- System Topology
- Latitude of Site
- Day of the Year

River Geometry - Existing and Unimpounded

- Cross-sectional Area
- Width of River
- River Mile

Main Stem

- Main Stem Boundary Inflows
- Main Stem Boundary Temperatures

Tributary

- Tributary and Point Source Flows
- Tributary and Point Source Temperatures

Meteorology

- Cloud Cover
- Dry Bulb Temperature
- Wind Speed
- Vapor Pressure of the Air near the Water Surface
- Atmospheric Pressure

AVAILABLE INFORMATION

Type of Data	*EPA's Available Information in Study Area*
Tributary Temperature	**19 Stations** **30 Year Record - Discontinuous - Grab Samples**
Mainstem Temperatures	**Scroll Case, Tailrace, Forebay of USACE Dams** **30 Year Record – Discontinuous – Daily Obs.**
River Geometry	**Existing Conditions: Approx. 100 profiles** **Natural Conditions: Approx. 150 profiles**
Flow	**22 USGS Gages** **30 Year Record – Continuous – Daily Observations**
Meteorology	**3 First Order Stations, 2 Local Air Temp Stations** **30 Year Record – Continuous – Hourly Observations**

Data Retrieval & Formatting Challenge

- Data Cornucopia
  - large scale, many monitoring locations
  - voluminous data
  - numerous formats, sample types, etc.
  - data gaps
  - outliers
- Making Data Usable for RBM10
  - adhoc utilities for formatting and calculating necessary input data

IMPORTANT ASSUMPTIONS

Important Assumptions

- **Meteorology**
  - Described by five regional weather stations
- **Mainstem Flow**
  - Constant elevation for impounded reaches except Grand Coulee
  - Leopold relations developed from gradually-varied flow methods for un-impounded reaches
- **Tributary Temperatures**
  - Mohseni relations developed from local air temperature and weekly/monthly river monitoring

Important Assumptions

- **Groundwater**
  - Hyporheic flow does not significantly change the cross-sectionally averaged temperature in un-impounded conditions
- **Measurement Model**
  - Tailrace monitoring represents best available measure of cross-sectionally averaged temperatures
  -

MODEL DEVELOPMENT

TERMINOLOGY

Identification	=	**Selection**
Calibration	=	**Parameter Estimation**
Verification	=	**Acceptance**

MODEL SELECTION

- 1-Dimensional, Time Dependent
- Estimates of Water Temperature from Process and Measurement Models Treated as Random Variables
- Mixed Lagrangian-Eulerian solution technique "Reverse Particle Tracking"
  - reduces error due to numerical dispersion
  - reduces numerical instability
  - reduces computational burden of uncertainty evaluation

PARAMETER ESTIMATION

- Identify parameters that govern rates of energy transfer in the system
  - Some are well known (e.g., solar declination)
  - Some are less well known (e.g., evaporation rates)
- Two parameters that are less known are estimated
  - evaporation rates
  - assignment of area covered by 5 meteorological stations

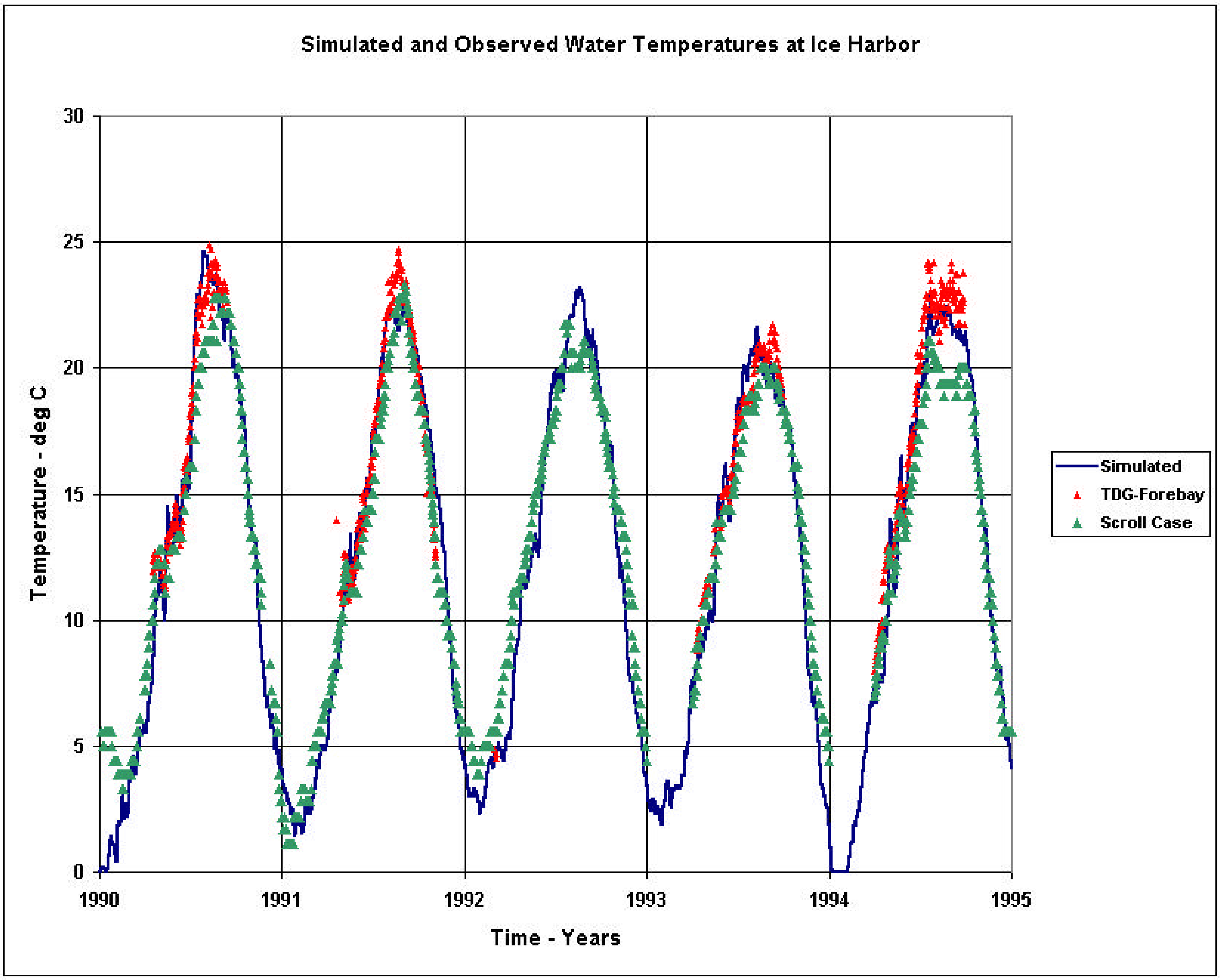
ACCEPTANCE CRITERIA

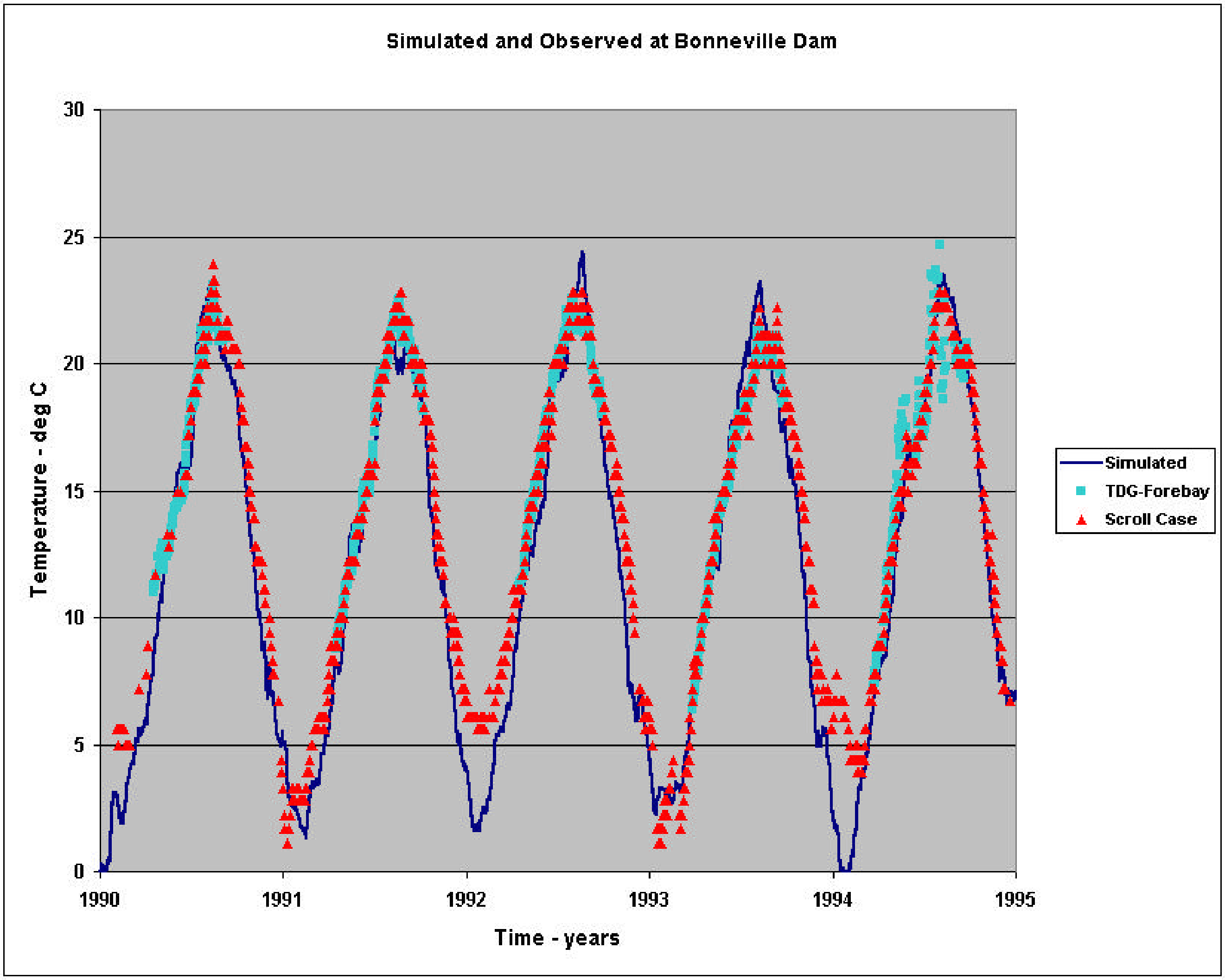
- Estimates for evaporation rates and meteorological station assignment are varied to satisfy criteria for model acceptance

- Acceptance criteria:

  - solutions are unbiased; and
  - error is uncorrelated in time

MODEL APPLICATION AND ACCEPTANCE


Simulated and Observed Water Temperatures at Ice Harbor
Temperature - deg C
0
5
10
15
20
25
30
1990
1991
1992
1993
1994
1995
Time - Years
Simulated
TDG-Forebay
Scroll Case



Simulated and Observed at Bonneville Dam
30
25
20
15
10
5
0
Temperature - deg C
1990
1991
1992
1993
1994
1995
Time - years
Simulated
TDG-Forebay
Scroll Case

Figure D-6. Regression of observed on simulated at Ice Harbor Dam 1990-1995

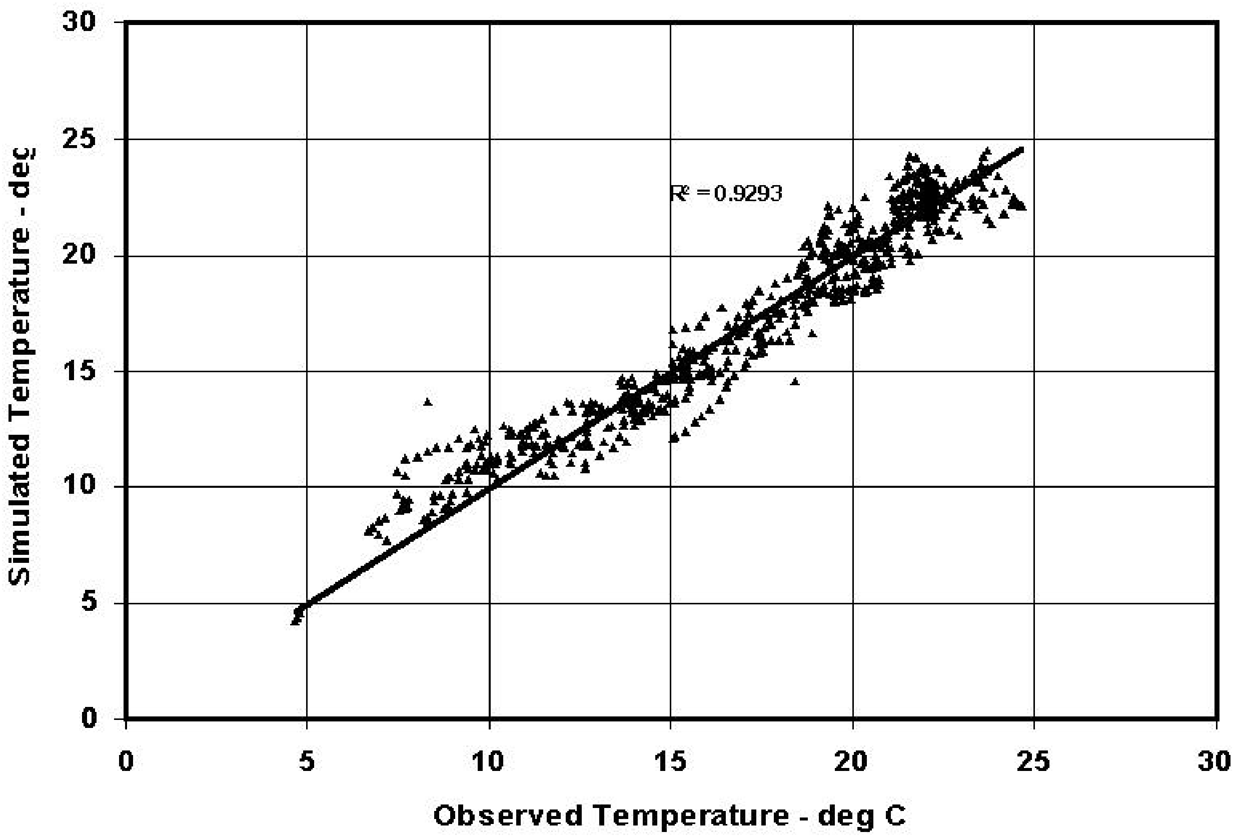
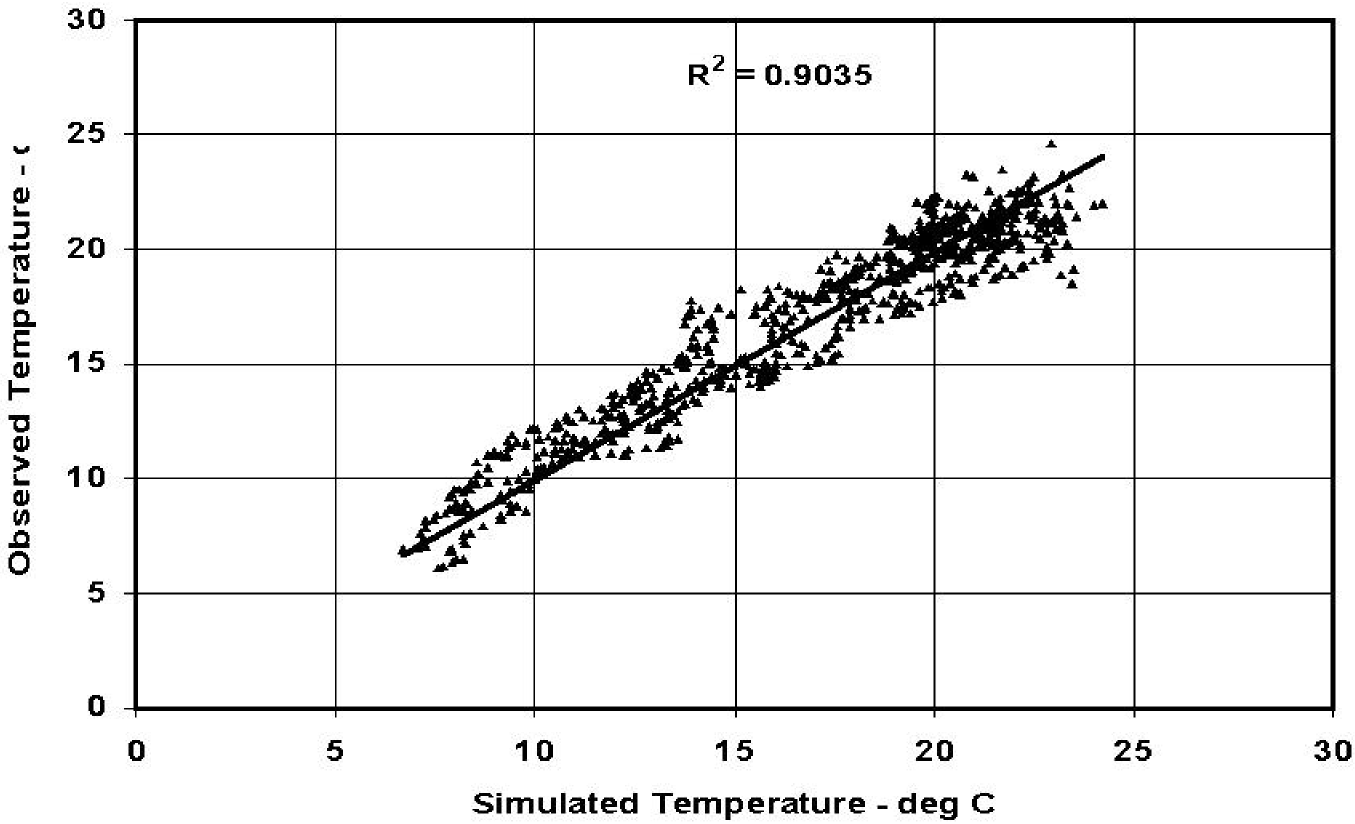


Figure D-5. Regression of observed on simulated at Bonneville Dam 1990-1995.



RBM10 Results for 1990-1994

Location	***Mean Difference (Obs-Sim)***	***Standard Deviation***
Snake River @Ice Harbor	0.05 deg C	1.2
Columbia River @Bonneville	0.04 deg C	1.3

Error Estimates from Other Studies

- **RISLEY (1997) - Tualatin River**
  Max Mean Difference = 3 Deg C
  Mostly < 1 Deg C

- **BATTELLE-MASS1 (2001) - Columbia River**
  RMS Error = 0.59 - 1.52 Deg C

- **HDR/PORTLAND STATE/IPC (1999) - Snake River**
  AME = 0.6-2.3 Deg C (1992 data)
  AME = 0.5-2.0 Deg C (1995 data)

- **CHEN (1996) - Grande Ronde River**
  Error = -2.20 - 8.28 Deg C (Summer Max)
  Error = -1.21 - 7.69 Deg C (Avg 7-day Max)